

Contemporary Subsidence and Ground Movement, Southwestern Ontario: Possible Bedrock Controls Affaissement et mouvements de terrain récents dans le sud-ouest de l'Ontario, probablement issus de la roche en place

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Résumé de l'article

Des mouvements de terrain, surtout par affaissement avec décrochement limité, se produisent de façon discontinue le long d'une zone de 8 km sub-parallèle à la St. Clair River, de Mooretown à Corunna, en Ontario. La zone de subsidence la plus méridionale se trouve sous la rivière, à 25 m du rivage canadien. La zone d'affaissement la plus longue se situe à [^] 75 m à l'est de la rivière et sa limite nord se situe de 250 à 300 m à l'est de la rivière. La subsidence a été à la fois brusque et graduelle, dans un cas, se produisant en une nuit et, dans l'autre, sur une période de deux ans. Dans les zones centrale et sud, la partie ouest (la plus près de la rivière) s'est affaissée de 20 à 40 cm. Dans le nord, toutefois, c'est la partie est qui s'est affaissée. Les fondations d'une maison ont subi des déplacements dextres de 1 et 5 cm le long de deux surfaces discontinues. Les mouvements de terrain ne ressemblent pas à des effondrements de surface. Des mouvements du socle résultant de la dissolution de calcaire ou de sel, des déplacements le long des structures du socle de Grenville ou une combinaison des deux pourraient expliquer le phénomène. La déformation observée pourrait, en raison de la formation d'un escarpement et des dommages faits aux bâtiments, avoir une origine néotectonique.

CONTEMPORARY SUBSIDENCE AND GROUND MOVEMENT, SOUTHWESTERN ONTARIO: POSSIBLE BEDROCK CONTROLS

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ABSTRACT Ground movement, principally subsidence with limited strike-slip displacement, occurs discontinuously along an 8 km-long, north-south zone which is subparallel to the St. Clair River and extends from Mooretown to Corunna, Ontario. The southern-most area of subsidence lies beneath the river, 25 m from the Canadian shore. The longest continuous interval of subsidence is ≤ 75 m east of the river and the northern limit is located about 250 to 300 m east of the river. Subsidence has been both abrupt and gradual, occurring overnight and over a two-year period. In the south and central areas the west side (the side closer to the river) has dropped 20 to 40 cm. However, in the north, the east side has subsided. The foundation of one home has been displaced 1 and 5 cm, in a right-lateral sense, along two discrete surfaces. The ground movements do not resemble surface slumping. Bedrock movement resulting from either dissolution of limestone or salt, displacements along Grenville basement structures, or a combination of the two may explain the phenomenon. The deformation observed, both in the production of scarps and damage to civil structures, may have neotectonic implications.

INTRODUCTION

From 1989 to 1991, temporally and spatially discontinuous subsidence has occurred along an 8 km-long linear trend, parallel to the St. Clair River, and extending north-northeast from Mooretown to Corunna in southwestern Ontario (Fig. 1). The movement has severed a municipal water main, domestic sewage and electrical lines, and has caused major structural damage to homes and a commercial dock. This linear trend of subsidence extends toward urban and industrial areas along the St. Clair River, a major navigable waterway. The bedrock near Windsor, Ontario, 60 km south of the study area, has undergone subsidence, attributed to local cavern collapse resulting from solution-mining for salt (Terzaghi, 1966) or natural dissolution (Nieto *et al.*, 1983). This paper addresses the details of the ground motion in the Mooretown-Corunna area in the context of mapped faults and the current ambient stress field.

GEOLOGICAL SETTING

The study area is, for the most part, rather featureless being underlain by deep-water lacustrine clays (Fitzgerald *et*

RÉSUMÉ Affaissement et mouvements de terrain récents dans le sud-ouest de l'Ontario, probablement issus de la roche en place. Des mouvements de terrain, surtout par affaissement avec décrochement limité, se produisent de façon discontinue le long d'une zone de 8 km sub-parallèle à la St. Clair River, de Mooretown à Corunna, en Ontario. La zone de subsidence la plus méridionale se trouve sous la rivière, à 25 m du rivage canadien. La zone d'affaissement la plus longue se situe à ≤ 75 m à l'est de la rivière et sa limite nord se situe de 250 à 300 m à l'est de la rivière. La subsidence a été à la fois brusque et graduelle, dans un cas, se produisant en une nuit et, dans l'autre, sur une période de deux ans. Dans les zones centrale et sud, la partie ouest (la plus près de la rivière) s'est affaissée de 20 à 40 cm. Dans le nord, toutefois, c'est la partie est qui s'est affaissée. Les fondations d'une maison ont subi des déplacements dextres de 1 et 5 cm le long de deux surfaces discontinues. Les mouvements de terrain ne ressemblent pas à des effondrements de surface. Des mouvements du socle résultant de la dissolution de calcaire ou de sel, des déplacements le long des structures du socle de Grenville ou une combinaison des deux pourraient expliquer le phénomène. La déformation observée pourrait, en raison de la formation d'un escarpement et des dommages faits aux bâtiments, avoir une origine néotectonique.

al., 1979a, b; Chapman and Putnam, 1984) which were deposited on the thick St. Joseph Till which mantles the low-relief Paleozoic bedrock surface. Relief on the clay plain appears to be limited to places where local streams and rivers have been incised into the surficial sediments. The Paleozoic bedrock is 1300 m thick and forms the southeastern limit of the Michigan Basin. Among the stratigraphic units in the Paleozoic sequence is the Devonian Detroit River Formation, which lies 100 m below the surface and in which there is extensive karst development in adjacent Michigan (Black, 1983). Further down is the Silurian Salina Formation, 333 to 787 m in depth, with soluble salt beds forming 151 m of this interval. The Salina has been subjected to solution-mining only 4.5 km northeast of the study area (Gilbert, 1963). The gently-dipping Paleozoic rocks are cross-cut by post-Devonian faults which provided structural traps for oil and gas in the permeable Dundee and Detroit River formations (Sanford *et al.*, 1985). Underlying the Paleozoic strata are Precambrian gneisses which have been sheared along the Grenville Front Tectonic Zone (GFTZ), a major structural boundary (Easton and Carter, 1990).

Seismically, the area is considered to be rather quiescent. The nearest reported seismic event was an earthquake of intensity III (Smith, 1962), 10 km north of the study area and

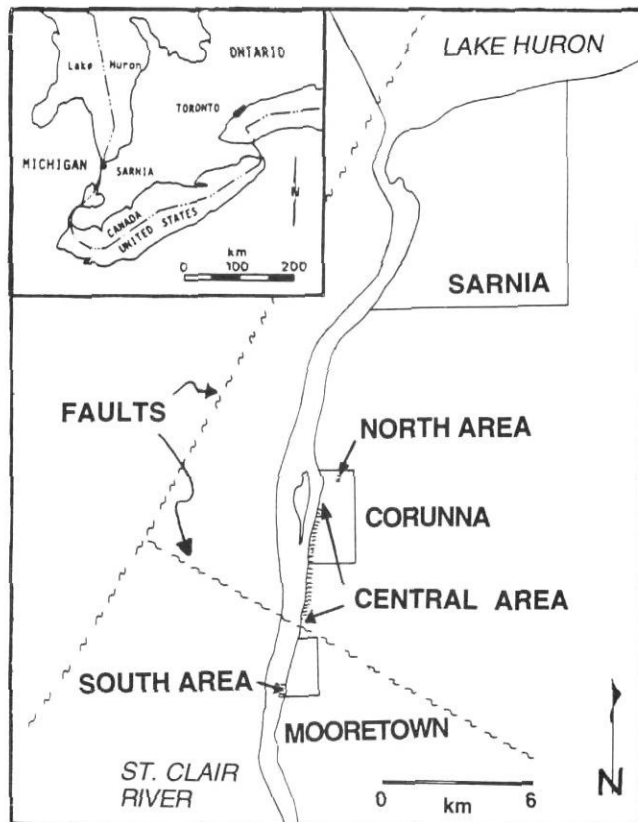


FIGURE 1. Locations of ground subsidence (hachure marks) and mapped faults (after Ontario Geological Survey, 1991).

Localisation des affaissements (hachures) et des failles (Commission géologique de l'Ontario, 1991).

spatially related to the GFTZ. The only others which are known to have affected the general region include earthquakes of intensity V near Detroit, 75 km to the southwest, and at Wenona (Bay City), Michigan, 160 km to the northwest (Keener, 1974).

NATURE OF GROUND MOVEMENT

In the study area, subsidence has occurred in three surficial geomorphologic settings which are: a) beneath the St. Clair River, b) along the slope of the river bank descending from the clay till plain to the river and c) on the clay till plain, 250 m east of the river bank. Two styles of ground movement have been recognized. The first occurred as an instantaneous drop of 20 to 40 cm near, and east of, the bank of the St. Clair River and produced a distinct north-northeast trending scarp with the west (river) side down, relative to the east side. The second, also trending north-northeast, developed progressively over at least a year and is marked by structural damage to buildings, though there was no scarp formation.

SOUTH AREA OF GROUND MOVEMENT (AREA 1)

The southern limit of recognized subsidence is located 500 m south of Mooretown (Fig. 1) where a commercial gravel dock, constructed of sheet piling driven into the river bed and extending 25 m into the St. Clair River, partly col-



FIGURE 2. Trace of the continuous scarp, visible as a dark strip of grass. Located 1 km north of Mooretown.

Tracé de l'escarpement continu, qui apparaît comme un ruban d'herbes sombre, situé à 1 km au nord de Mooretown.

lapsed overnight. Estimates from the damaged sheet piling and rebuilding efforts suggest 40 to 50 cm of subsidence. The site of ground movement is 20 to 25 m offshore in the St. Clair River where the water depth abruptly increases from 2 to 8 m toward the centre of the river.

CENTRAL AREA OF GROUND MOVEMENT (AREA 2)

The central area of ground subsidence lies 2 km north of area 1 (Fig. 1). It extends in a north-northeasterly direction from just north of Mooretown to the village of Corunna, a distance of 6 km. The southern 1.5 km interval, nearest the village of Mooretown, is marked by a distinct, continuous scarp (Fig. 2). In contrast, the northern 4 km interval is discontinuous and no clear scarp was produced.

All ground subsidence in this area has occurred along a moderate to steep slope which has an approximately 15 m vertical drop over a lateral distance of less than 75 m. The subsidence-induced scarp is not confined to any particular part of the slope, but occurs at the top, in the middle and at the base, which is approximately 1 m above the level of the river high-water mark. Sinking on the southern 1.5 km section was first noticed as episodic, instantaneous drops on a north-northeasterly line that produced the 30 to 40 cm scarps. Short sections of scarp propagated along strike, eventually coalescing with adjacent drops to form a laterally continuous feature. Attempts by residents to level the relief by adding topsoil have not obscured the scarp line which remains visible as a distinct dark grass strip (Fig. 2), reflecting increased moisture and nutrient input along the ground rupture. One home was structurally damaged (Fig. 3), and was subsequently replaced. Adjacent to the damaged home, a buried electrical cable and waste line to a septic tank were severed by an instantaneous 20-30 cm drop. The septic system has been reconnected and severed again at least twice.

The northern section of the area 2, extending into the community of Corunna, lacks a laterally continuous scarp. It is recognized mainly by damage to buildings and truncation of a municipal water main. The water main was broken in two



FIGURE 3. A structurally damaged home with a fractured concrete foundation and a downwarped overhang. Note that the supporting columns and the walls are no longer vertical. This house was replaced with a new one upslope, and away from the area of ground movement.

Structures d'une maison endommagées avec fracture dans les fondations de béton et affaissement. Noter que les poutres de soutien et les murs ne sont plus verticaux. Une nouvelle maison située plus haut, loin des mouvements de terrain, remplace la maison endommagée.

locations where it crossed an area of subsidence. At each break, the pipe ends were reported to have curved toward the river.

The poured concrete foundation of a river front home showed 1 cm of right-lateral slip, along a north-south break, in addition to a vertical drop of 25-30 cm with the west (river) side down. Masonry supporting the attached porch of the same building, located 7 m west of the displaced foundation, underwent a 5-cm parallel strike-slip displacement without any apparent vertical offset (Fig. 4).

NORTH AREA OF GROUND MOVEMENT (AREA 3)

The most northerly site of ground subsidence lies 250 to 300 m east of the St. Clair River (Fig. 1). Two structurally damaged homes define a north-northeasterly trend which parallels, but does not lie along the projection of, the line through the central or southern areas. Between this linear trend and the river the ground is undisturbed. Ground movement, recognized by damage to the two homes, appeared as progressive subsidence without rapid drops or scarp development. Here the observed movement is east side down relative to the west side, in contrast to the movement observed to the south.

DISCUSSION

At present the origin of the ground movement, observed only in the surficial sediments, is uncertain. Slumping into the St. Clair River seems unlikely because, in area 3 east of the river, the east side is downthrown and, in areas 1 and 2 where the sense of displacement is consistent with slumping into the river, neither a slump décollement, arcuate slump scar, nor rotational features have ever been observed. Furthermore, walls, buildings and river pilings remained vertical, even with

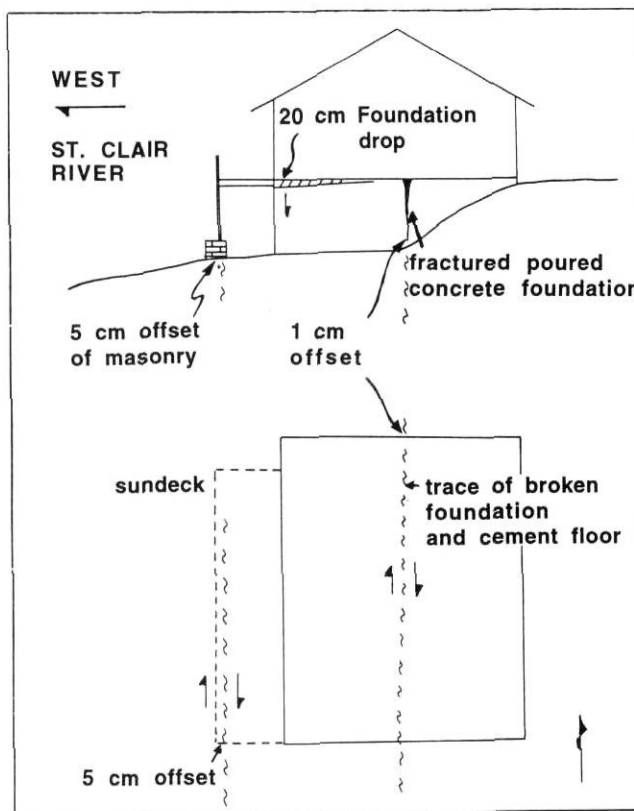


FIGURE 4. Plan (bottom) and cross section (top) schematic views of the home which underwent strike-slip displacement of a poured concrete foundation along with a 25 to 30 cm vertical displacement. There was parallel strike-slip displacement of masonry adjacent to the house.

Coupe (haut) et plan (bas) schématiques de la maison dont les fondations de béton ont été fracturées avec rejet vertical de 25 à 30 cm. On a observé un décrochement parallèle sur un ouvrage en pierre près de la maison.

vertical displacements of 30-50 cm. Where a scarp line developed, it is oblique, rather than parallel to, the river.

Subsidence involving the bedrock is strongly suspected. It may be due to dissolution of either the relatively shallow limestone or the deeper salt beds of the Salina Formation. Alternatively, the displacement may have resulted from tectonic displacements originating along the GFTZ.

The stratigraphic unit closest to the surface, and susceptible to dissolution, is the calcareous Detroit River Formation which, in the study area, is overlain by 45 m of Quaternary sediments (Fitzgerald *et al.*, 1979b) and 15 m of the Kettle Point Shale (Raven *et al.*, 1990). Karst within the Detroit River Formation has been recognized extensively throughout the Michigan Basin in the United States with extensive surface exposures present in northern Michigan (Black, 1983). A well, 6.5 km north of the study area, has a vertical void of 18 cm, where limestone has been removed by solution (Raven *et al.*, 1990).

Dissolution may have also occurred in the salt-bearing Silurian Salina Formation, a phenomenon known to have caused ground subsidence in southwestern Ontario (Terzaghi, 1966) and in New York State (Phillips, 1955). At

Sarnia, 14 km north of the study area, a breakwall along the St. Clair River subsided at the site of earlier solution-mining for salt. Ground subsidence, adjacent to the Detroit River near Windsor, has also occurred near solution mining sites (Terzaghi, 1966; Nieto *et al.*, 1983). In one case a circular depression sagged over a 5-year period, beginning as a 6 cm/year subsidence and ending with a catastrophic collapse, 150 m in diameter and 7.5 m deep (Terzaghi, 1966). The nearest solution-mining to the study area lies 4.5 km north of Corunna, and east of the north-northeast subsidence trend, thus the subsidence in the Mooretown-Corunna area is not related to salt mining.

Dissolution of limestone and salt has been recognized both in Ontario (Sanford *et al.*, 1985) and Michigan (Prouty, 1983) as having taken place preferentially along faults. The faulting, and associated dissolution, were episodic during the Paleozoic Era and formed in response to periods of regional, intracratonic stress application (Prouty, 1983; Sanford *et al.*, 1985). The faults acted as conduits for fluids along which the Salina Formation salt has been removed. At Petrolia, 25 km east of the study area, little, if any, dissolution (Sanford *et al.*, 1985) has taken place along the north-northeast trending faults, although Devonian-age lime muds have filled the voids created on east-west and northwest-trending faults (Sanford *et al.*, 1985).

Two faults, one of which trends predominantly north-northeast and is subparallel to the approximately north-south trend of the St. Clair River, have been mapped in the immediate Mooretown-Corunna area (Ontario Geological Survey, 1991). The other is oriented approximately west-northwest. The north-northeast oriented fault is of regional extent and parallels both the GFTZ (Easton and Carter, 1990) and the subsidence trend in the study area.

Right lateral displacement (Fig. 4) along a north-northeast trend is consistent with the current ambient stress field in which the greatest principal horizontal compressive stress is oriented N54°E (Plumb and Cox, 1987). High lateral stress, associated with karst collapse, has been documented at three sink holes near Windsor (Nieto *et al.*, 1983). The removal of material by dissolution along a structural break might be expected to provide the focus for stress release which, in the current stress field, could be accommodated by dextral slip along north-northeast oriented faults. The 1922 intensity III earthquake (Smith, 1962), 10 km to the north, appears to lie near the projected strike of the linear zone of subsidence in the Mooretown-Corunna area. An immediate, detailed investigation is required to verify or refute the suspected cause of subsidence, as interpreted in this paper, not only because of the neotectonic implications of the deformation, but because of the on-going risk to people and property.

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